Supporting Information: A Low Cost and Simple Demonstration of Freezing Point Depression and Colligative Properties with Common Salts and Ice Cream

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ABSTRACT
This material includes two student handouts

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Experimental Protocol/Student Handout

PART A: Determination of the Freezing Point Depression of Aqueous Salts

PURPOSE

To observe the characteristics of freezing point depression by measuring the change in the freezing point of a solvent when solute is added.

OBJECTIVES

After completing this experiment, you will be able to:

- Demonstrate freezing point depression is a colligative property
- Relate freezing point depression to apparent molality

MATERIALS

- 2 Styrofoam cups
- 1 Thermometer
- 1 Cardboard lid
- Sodium chloride (NaCl) solutions at 1 *m*, 3 *m*, and 5 *m*
- Sodium chloride ice cubes (4 each) at 1 *m*, 3 *m*, and 5 *m*
- Magnesium sulfate ($MgSO_4$) solutions at 1 *m*
- Magnesium sulfate ice cubes (4 cubes) at 1 *m*
- Calcium chloride ($CaCl_2$) solutions at 1 *m*
- Calcium chloride ice cubes (4 cubes) at 1 *m*

BACKGROUND

Colligative properties are properties that depend on the number of solute particles present rather than the identity of the solute. Examples of these properties include osmotic pressure, boiling point elevation, and freezing point depression. The change in the freezing point of a solvent can be determined by

$$\Delta T_f = k_f i m \qquad (1)$$

where k_f is the molal freezing point depression constant, *m* is the molality of the solution, and i is the Van't Hoff factor, or the number of solute particles dissolved per formula unit. For example, one unit of NaCl dissolved in water will produce one sodium ion and one chloride ion, so there are two solute particles per unit of dissolved NaCl (i = 2).

In this experiment, the freezing points of NaCl solutions at various concentrations will be compared. The freezing point predicted by the equation will be compared to the measured temperature. The literature value for the k_f of water is -1.86 °C/m. The freezing points of 1 *m* solutions containing different salts will be compared as well to demonstrate apparent molality and the Van't Hoff factor.

PROCEDURE

1. Measurement of sodium chloride solutions at various concentrations

1.1. Arrange the calorimetry setup, including the Styrofoam cup, cardboard lid, and thermometer. Read through the full procedure for step 1 before retrieving the needed materials. Use equation 1 to predict the freezing point of each solution in the table below.

1.2. Retrieve the solutions labeled 1 *m* NaCl and the ice cube trays with the corresponding sodium chloride concentrations. Once you retrieve these materials, proceed through the procedure quickly to avoid melting the ice cubes before using them.

1.3. In a Styrofoam cup, place 3 to 4 of the 1 *m* NaCl ice cubes and pour enough 1 *m* NaCl solution to sufficiently submerge the ice cubes. The cup should be ~¾ full.

1.4. Cover the cup with a cardboard lid and insert a thermometer through the hole in the lid. Stir the solution using the thermometer. Be sure to not poke through the cup with the thermometer. Once the setup is assembled, return the unused ice cubes to the appropriate container.

1.5. In the table below, record the temperature of the solution once the reading on the thermometer stabilizes and stops dropping.

Note: the reading may briefly stabilize at temperatures before the freezing point is reached. The correct temperature will remain constant for around one minute.

1.6. Once the ice completely melts in the cup, refill the used ice cube tray slots with the solution in the cup. Pour the remaining solution back into the solution bottle.

1.7. Repeat steps 1.2-1.5 with the 3 *m* and 5 *m* NaCl ice cubes and solutions. If there are extra materials, the steps can be repeated while the first is happening if an eye is kept on the initial solution.

2. **Measurement of various salt solutions at 1 molal**

   2.1. Retrieve the solutions labeled 1 *m* $MgSO_4$, 1 *m* $CaCl_2$, and the ice cube trays with the corresponding salt concentrations.

   2.2. Repeat steps 1.2-1.5 with the 1 *m* $MgSO_4$ and $CaCl_2$ ice cubes and solutions.

DATA

Table S1 Data Table

Salt solution	Predicted Freezing-Point (°C)	Measured Freezing-Point (°C)
NaCl (5 *m*)		
NaCl (3 *m*)		
NaCl (1 *m*)		
$MgSO_4$ (1 *m*)		
$CaCl_2$ (1 *m*)		

Insert the NaCl data from the first table into the spreadsheet provided. Be sure to make a copy of the google sheet before inputting your data. Using equation 1 and the slope of the best-fit line for the measured data, calculate the molal freezing point depression constant, k_f, of water. Compare this value to the literature value, -1.86 °C/m.

REFLECTION

In the second part of this experiment, you will be asked to use salted ice cubes to help make ice cream. Based on the given costs of each salt by weight, choose a salt and concentration that would be best suited for making the thickest ice cream possible.

Sodium chloride = $0.00054/g   Magnesium sulfate = $0.0016/g   Calcium chloride = $0.0020/g

Experimental Protocol/Student Handout

PART B: Application of Freezing Point Depression to Make Ice Cream

PURPOSE

To evaluate and apply the concepts of freezing point depression by making ice cream.

OBJECTIVES

After completing the experiment, you will be able to:

- Apply freezing point depression to real life scenarios
- Evaluate concentration, solubility, and cost with respect to a given problem

MATERIALS

- Small plastic bag containing ice cream mixture
- Large plastic bags containing salted ice cubes
- Plastic spoons
- Winter gloves
- Sodium chloride ice cubes (1, 3, and 5 molal)
- Magnesium sulfate ice cubes (1 molal)
- Calcium chloride ice cubes (1 molal)

PROCEDURE

1. Read through the full procedure before beginning. Retrieve a large plastic bag containing the salted ice cubes assigned to you.
2. **All students will perform this step at the same time.** Place the ice cream bag into the ice cube bag. Put on a pair of winter gloves and knead the plastic bags with your hands. Continue to knead the bag until you are confident the ice cream is entirely rock solid or until another student says they have finished. Once the first student in the room reaches this point, everyone else will stop kneading immediately. If you finish before any other students, immediately let the TA know.

   Note: ensure the ice cubes are surrounding the ice cream bag while kneading.

3. Once you have stopped kneading, scoop some of the ice cream (less than a ping pong ball's worth) into a spoon. Try to scoop the ice cream from the most solid portion of the bag. Ready a stopwatch, then flip the spoon upside down. Start the stopwatch at the moment the spoon is flipped and stop the time when the mass of ice cream falls off the spoon. Record this time below. Ask your classmates for their measurements to collect data for each salt concentration.

Time before ice cream fell: ______ ______ ______ ______ ______

1 *m* NaCl | 3 *m* NaCl | 5 *m* NaCl | 1 *m* $MgSO_4$ | 1 *m* $CaCl_2$

REFLECTION

1. Based on the result of your experiment, did your salt concentration produce satisfactory results? Predict why your salt did or did not produce the desired results.

2. If asked to repeat the experiment, which salt, and which concentration would you choose? Explain.